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13. ABSTRACT
Most practical dynamical systems are formulated by hybrid uncertain delayed systems that consist of mixed continuous and discrete uncertain subsystems with state and/or input delays. For improving the performance of the delayed hybrid systems, well-established control theory and design methods are available in the continuous-time domain to find analog controllers. The resulting analog controller is required to be replaced by a digital controller for better reliability lower cost, smaller size, more flexibility and better performance.

In this research, we have successfully accomplished the following research subjects: (1) Digital/analog model conversions of linear hybrid interval systems with unknown-but-bounded uncertain parameters; (2) Digital modeling and control of linear continuous-time systems with state, input and output delays; (3) Development of digital redesign techniques for digital control of cascaded linear hybrid interval systems; (4) Development of PAM (Pulse-Amplitude-Modulated) and PWM (Pulse-Width-Modulated) digital controllers for linear hybrid interval systems; (5) Design of digital PAM tracker for nominal chaotic orbits; (6) Interval Kalman filtering for linear stochastic uncertain systems; (7) Fuzzy-model-based self-tuning controller for nominal chaotic systems; (8) Model conversions and optimal control of 2D (2 Dimensional) nominal systems; (9) GA (Genetic Algorithm)-based optimal digital controllers for linear hybrid interval systems.

14. SUBJECT TERMS
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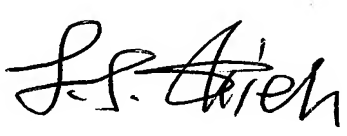

Enclosure 3

Interval Method for Analysis and Design of Hybrid Uncertain Systems

(I) Summary of Research Results

(1). Sheen, I.E., J.S.H. Tsai and L.S. Shieh, "Optimal Digital Redesign of Continuous Time Systems with Input Time Delay and/or Asynchronous Sampling," Journal of the Franklin Institute, Vol. 335B, No. 4, pp.605-616, May 1998.

(2). Zimpfer, D.J., L.S. Shieh, and J.W. Sunkel, " Digitally Redesigned Pulse-Width Modulation Spacecraft Control," AIAA Journal of Guidance Control and Dynamics. Vol. 21, No. 4, pp.529-534, July 1998.

(3). Shieh, L. S., W. M. Wang and J.S.H. Tsai, "Digital Redesign of H-infinity Controller Via Bilinear Approximation Method for State-Delayed Systems," International Journal of Control, Vol. 70, No. 5, pp.665-683, July 1998.

(4). Wang, S.G, S. Lin and L.S. Shieh, "Several Simple Sufficient Conditions for Hurwitz and Schur Stability of Interval Matrices," Control and Intelligent Systems, Vol. 26, No. 1, pp.28-33, 1998.

(5). Chen, G., Q. Xie and L.S. Shieh, "Fuzzy Kalman Filtering," Journal of Information Science, Vol. 109, pp.197-209,1998.

(6). Shieh, L.S., W.M. Wang and M.K. Appu Panicker, "Design of PAM and PWM Digital Controllers for Cascaded Analog Systems," ISA Transactions, Vol. 37, pp.201-213, 1998.

(7). Tsai, J.S.H., Y.P. Chang and L.S. Shieh, "Optimal Digital Redesign of a Cascaded Continuous-Time System with Input Time Delays," JSME International Journal Series C, Vol. 41, No. 3, September 1998.

(8). Shieh, L.S., W.M. Wang and G. Chen, "Discretization of Cascaded Continuous-Time Controllers and Uncertain Systems," Circuits, Systems, and Signal Processing, Vol. 17, No. 5, pp.591-611, 1998.

(9). Leang S. Shieh, Weimin Wang and Jason S.H. Tsai, "Optimal Digital Design of Hybrid Uncertain Systems Using Genetic Algorithms," Proc. IEE, Control Theory and Applications, Vol. 146, pp.1-21, March 1999.

(10). Wei-Min Wang, Shu-Mei Guo and Leang-San Shieh, "Discretization of Cascaded Continuous-time Controllers for State and Input Delayed Systems," International Journal of Systems Science, Vol. 30, No. 4, pp.1-10, 1999.

(11). Leang-San Shieh, Udayini Dikkala and C. Hwang, "Model Conversion and Redesign of a Sampled-Data Uncertain System using Simpson's Rule", J. of the Chinese Institute of electrical Engineering Vol. 6, pp.179-194, 1999.

(12). Jason Sheng-Hong Tsai, Chang-Chi Liu and Leang-San Shieh, "Multi-rate Sampled-data Control of the Cascaded Continuous-time Input Time-delay Interval System: Digital Redesign Approach," J. of the Chinese Institute of Electrical Engineering, Vol. 6, No. 4, pp.315-327, 1999.

(13). Guanrong Chen, Jialiang Lu, Brent Nicholas and Swatiprakash M. Ranganathan, "Bifurcation Dynamics in Discrete-time Delayed-feedback Control Systems," International Journal of Bifurcation and Chaos, Vol. 9, No. 1, 287-293, 1999.

(14). Guanrong Chen, Zhongying Chen and Yuesheng Xu, "Numerical Computation of a Damped Slewing Beam with Tip Mass," Communications in Numerical Methods in

Engineering, 15, 249-2619, 1999.
(15).Daniel W. Berns, Jorge L. Moiola and Guanrong Chen, "Feedback Control of Limit Cycle Amplitudes from A Frequency Domain Approach," Automatica, Vol. 34, No. 12, pp. 1567-1573, 1998.
(16).K. S. Park, J.B. Park, Y.H. Choi, T.S. Yoon and G. Chen, "Generalized predictive Control of Discrete-time Chaotic Systems," International Journal of Bifurcation and Chaos, Vol. 8, No. 7, 1591-1597, 1998.
(17).Joo, Y.H., L. S. Shieh and G. Chen, "Hybrid State-Space Fuzzy-Model-Based Controller with Dual-Rate Sampling for Digital Control of Chaotic Systems," IEEE Trans. On fuzzy Systems, Vol. 7,No. 4, pp.384-408, Aug. 1999.
(18).J. Ortiz and G. Chen, "Intelligent Control of a Planning System for Astronaut Training," IEEE Transactions on Aerospace and Electronic Systems, Vol. 35, No. 3, pp.1055-1070, July 1999.
(19).L. Chen and G. Chen, "Fuzzy Predictive Control of Uncertain Chaotic Systems Using Time Series," International Journal of Bifurcation and Chaos, Vol. 9, No. 4, pp.757-767, 1999.
(20).Y. C. Hsu and G. Chen, "Fuzzy Dynamical Modeling Techniques for Nonlinear Control Systems and Their Applications to Multiple-Input, Multi-Output (MIMO) Systems," Fuzzy Theory Systems: Techniques and Applications, Vol. 1, pp.47-86, 1999.
(21).G. Chen and Xinghuo Yu, "On Time-Delayed Feedback Control of Chaotic Systems", IEEE Trans. Circuits and Systems, Vol. 46, No. 6, pp.767-772, June 1999.
(22).Li, J.S., J.S.H. Tsai and L. S. Shieh, "Optimal Control for Two-Dimensional Linear Systems with Variable Coefficients", Asian Journal of Control, Vol. 1, No. 4, pp. 245-257, December 1999
(23).Chen, C. W., J.S.H. Tsai and L. S. Shieh, "Two-Dimensional Discrete-continuous Model Conversion", Circuits, System, and signal Processing, vol. 18, No. 6, pp. 565-585, December 1999
(24).Guo, S.M., W.Wang and I.S. shieh, "Discretization of Two Degree-of Freedom Controller and System with State, Input and Output Delays", Proceedings of IEE, Part D, Control Theory and Applications, vol. 147, No. 1, pp. 87-96, January 2000
(25).Guo, S.M., L.S. Shieh, G. Chen and M. Ortega, "Ordering Chaos in Chua's Circuit: A sampled-Data Feedback and Digital Redesign Approach", International Journal of bifurcation and Chaos, vol. 10, No. 8, August 2000
(26).Shieh, L. S., W.M. Wang, J. Bain and J.W. Sunkel, "Design of Lifted Dual-Rate Digital Controllers for the X-38 Vehicle", AIAA, Journal of Guidance, Control & Dynamics, vol. 23, No. 4, pp. 500-512, July-August 2000
(27).Guo, S. M., L. S. Shieh, G. Chen and C.F. Lin, "Effective Chaotic Orbit Tracker: a Prediction-Based Digital Redesign Approach," IEEE Trans. on Circuits and Systems-I: Fundamental Theory and Applications, Vol. 47, pp. 1557-1570, 2000
(28).Wang, X.F. and G. Chen, "Chaotification via Arbitrarily Small Feedback controls: Theory, Method and Applications", Int. J. of Bifurcation and Chaos, Vol. 10, pp. 549-570, 2000
(29).Chen, L., G. Chen and Y. W. Lee, "Fuzzy Modeling and Adaptive Control of Uncertain Chaotic Systems", Information Sciences, Vol. 121, pp. 27-37, 1999
(30).Guan, Z.H., G. Chen and Y. Qin, "On Equilibria, Stability and Instability of Hopfield

Neural Networks", IEEE Trans. Neural Networks, Vol. 11, pp. 534-540, 2000.
(31).Chen G., "What Does Chaos have to Do With Systems and Control Engineering?", Journal of Systems Science and Complexity, Vol. 14, No. 1, pp.31-39, 2001.
(32).Wang, X.F., G. Chen and X. Yu, "Anticontrol of Chaos in Continuous-time Systems via Time-delay Feedback", Chaos, Vol. 10, No. 4, pp. 771-779, 2000.
(33).Tang, W., G. Chen and R. Lu, "A Modified Fuzzy PI Controller for a Flexible-joint Robot Arm with Uncertainties", Fuzzy Sets and Systems, Vol. 118, pp.109-119, 2001.
(34).Berns, D.W., J.L. Moiola and G. Chen, "Detcting Period-doubling Bifurcation an Approximate Monodromy Matrix Approach", Automatica, Vol. 37, pp.1787-1795, 2001.
(35).Hsu, Y.C., G. Chen and H.X. Li, "A Fuzzy Adaptive Variable Structure Controller with Applications to Robot Manipulators", IEEE Trans. on Systems, Man and Cybernetics, Part B, Cybernetics, Vol. 31, pp.331-340, 2001.
(36).Shieh, C.S., J.S.H. Tsai, L.S. Shieh and Y.Y. Sun, "A Genetic Approach to Hybrid Control of Sampled-Data Uncertain Systems with Input Time Delay", International Journal of Computers and Electrical Engineering, Vol. 27, pp.395-417, 2001.
(37).Guo, S.M., L.S. Shieh, C.F. Lin and J. Chandra, "State-Space Self-Tuning Control for Nonlinear Stochastic and Chaotic Hybrid Systems," International Journal of Bifurcation and Chaos, Vol. 11, No.4, pp.1079-1113, April 2001.
(38).Hwang, C., J.J. Chen and L.S. Shieh, "A New Approach to Design Optimal PID Controllers with Minimum Quadratic Cost Criteria", J. Chinese Institute of Chemical Engineering, Vol. 32, No. 2, pp.163-175, 2001
(39).Guo, S.M., L.S. Shieh, G. Chen and N.P. Coleman, "Observer-Type Kalman Innovation Filter for Uncertain Linear Systems", IEEE Trans. on Aerospace and Electronic Systems, Vol. 37, No.4, pp.1-10, October 2001.

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(III) Report of inventions

None